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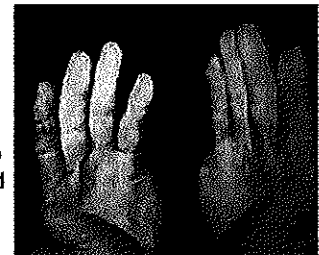
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## Acquisition Safety - Vibration

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### Introduction

The Navy cares deeply about protecting the safety and health of its greatest resource - its people. In today's workplaces, there exist many potentially serious occupational hazards. Some hazards, like noise-induced hearing loss and heat stress, are well known, heavily reported, and well documented. Much less is known about other workplace perils, which can produce serious, irreversible, and unsuspected diseases. *Occupational Vibration*, affecting eight to ten million people in the U.S. alone, is one of these lessobvious workplace hazards. Because Navy Leadership is concerned about the safety and health of its military and civilian workers, they are working hard to address this under-recognized occupational health problem through acquisition of safe, cost-effective, and performance-improving designs and equipment. This section of the Acquisition Safety website addresses the vibration issue uniquely and in depth. Included are the potential health effects of uncontrolled vibration and ongoing efforts to control this risk to Navy personnel. Also provided are best business practices and technical assistance for acquisition (research, development, design and procurement) of designs and equipment that will maximize productivity and operational effectiveness while protecting operators and maintainers of this equipment.



Hands of vibrating pneumatic hand-tool operator in later stages of irreversible Hand Arm Vibration Syndrome1

\* Copyright 1990, D.E. Wasserman, Inc.; Image of hands (not U.S. Navy worker) used with permission.

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### Background

Continuous exposure to excessive levels of vibration can cause irreversible damage to the human body. Workers who continually interact with machinery are affected to some degree by occupational vibration. Vibration exposure can be caused by use of poorly designed equipment and tools, which do nothing to attenuate vibration exposures. Two different types of vibration exposures - segmental (hand/arm) and whole body - affect the health and safety of some eight million U.S. workers. What Is Vibration?



Rare case of gangrene in hands of vibrating pneumatic hand-tool operator at terminal stage of irreversible Hand Arm Vibration Syndrome2

\* Copyright 1990, D.E. Wasserman, Inc.; Image of hands (not U.S. Navy worker) used with permission

A common category of segmental vibration exposure, affecting two million workers, is called Hand-Arm Vibration (HAV). This type of vibration exposure is caused by the regular use of vibrating pneumatic, electric, hydraulic, or gasoline-powered hand tools. Excessive HAV exposure can produce an irreversible condition of the hands called Hand-Arm Vibration Syndrome, or HAVS. (Click here to learn more about HAVS.)

Workers using manual grinders, swing grinders, cutting tools and similar equipment may be susceptible to HAVS. Table1 shows HAV exposures of U.S. Navy personnel.

A second type of vibration exposure, affecting six million workers from "head-to-toe," is called Whole-Body Vibration, or WBV. Whole-Body Vibration may occur in workers who regularly operate trucks, buses, heavy equipment, forklift trucks, trains, helicopters, rotary and fixed wing aircraft, ships, etc. Both health and safety problems may arise from WBV. The body becomes tuned to and amplifies some WBV frequencies. The safety concern is that under these circumstances operators can experience a loss of vehicle control due to vibrations forcing their hands away from the steering wheel and other controls. Table 2 shows potential WBV exposures of U.S. Navy personnel. (Click here to learn more about WBV.)



Regular exposure to WBV from heavy equipment can lead to lower back pain in equipment operators

Disabled workers suffering from HAVS and/or WBV-related degenerative disc disease are not as productive as employees who are not so affected. Uncomfortable workers may subvert built-in safety

mechanisms that they feel hinder them from performing their jobs quickly and easily, for example by using ill-fitting anti-vibration gloves, hearing protection, etc. Additionally, pain may cause fatigue and loss of concentration. These factors can contribute to workplace accidents, which can mean personnel injuries, even deaths. Aside from costs for treatment and rehabilitation, injuries mean lost time and productivity on the job. Accidents also result in time and material costs when equipment has to be repaired or replaced and operations are delayed or cancelled.

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## Relevance of Vibration Control to Acquisition

Acquisition managers and design engineers should continue to consider the potential negative impact of excessive vibration on mission performance, direct acquisition expenditure (acquisition life cycle cost), delivery schedule, and total ownership costs (TOC = lifecycle cost plus infrastructure support costs). Optimal use of existing technology can reduce risk factors and produce a superior product while protecting the safety and health of system operators/maintenance personnel. Prevention of vibration hazards has high return on investment in avoided workers' compensation for all areas of acquisition - during construction, maintenance, and disposal.



Full-finger protected AntiVibration Gloves, which meet: ANSI/ISO standards

Acquisition managers and design engineers are strongly encouraged to use and purchase, as applicable, "air ride" seats for Whole-Body Vibration situations requiring effective attenuation in the vertical (up-down) direction, fore-aft (front to back) direction, and sway (side to side) direction.

This technology has been highly developed and used in the transportation industry. Similarly, for Hand-Arm Vibration maximum safety, health, and performance requirements, acquisition managers are strongly encouraged to purchase AntiVibration, ergonomically designed power tools. These tools have numerous applications commonly found in both ship and base installations. Equally encouraged is the purchase of full-finger protected AntiVibration Gloves, which meet or exceed domestic/international standard: ANSI S3.40-2002 - ISO 10819.

## Potential Effects of Excessive Equipment Vibration on Acquisition Projects

**Whole Body Vibration (WBV)** - Equipment that creates excessive vibration can adversely affect the programs for building and buying equipment and vehicles and the life cycle costs for their operation. Vibration transmitted to operators and other occupants can impair their comfort, performance, and visual acuity and in extreme cases, even the ability to control a vehicle or aircraft. Whole body vibration in the range of 4 Hz vertical and 1-2 Hz side to side will create loss of control for vehicle operators. This is a resonant frequency (the range of motion is increased rhythmically with this frequency) and operators will be literally unable to control the vehicle.



Whole Body Vibration can cause operator to lose control of a vehicle

Designs that avoid this pitfall will be more effective and operate at reduced cost and risk. Excessive vibration is also likely to degrade equipment and can be an indicator of wear or impaired equipment condition. Fortunately, the control measures often have relatively low costs. For example, vibration control seats for vehicles are available for \$400 to \$500 each. Good vibration control is a hallmark of well-designed equipment in applications ranging from ventilation systems to engine mounting.

Control of vibration and noise is considered mission essential for many ships and certain land-based equipment because it reduces the vulnerability of their detection by the enemy. Lack of attention to vibration and noise control in the design phase can result in products that do not meet performance requirements and require costly re-design and schedule delays. This was the case for a minesweeper (ship designed to detect mines) that required improved mounting (isolation) of its engines, acoustical

insulation, and other controls to reduce transmitted vibration to an acceptable level. The immediate impact on the first ship of this class was increased cost and delay required for re-engineering. But, the end result was a much quieter vessel that was healthier and safer to operate.

**Hand Arm (Segmental) Vibration (HAV)** - Tools and processes that create excessive hand-arm vibration to users (workers) may have an impact on production and maintenance, which may impact schedule or cost. Products may be more costly to produce and maintain due to effects of HAV on skilled production and repair workers. Aircraft (especially airframes) and ship production include many processes that may create risks for hand-arm vibration in manufacturing workers. This is also a design and production issue related to quality control. For example, better castings will reduce the need for rework in the cleaning/finishing department where excess material is ground off.



Better tools and work process layout almost always yield results in productivity. This is

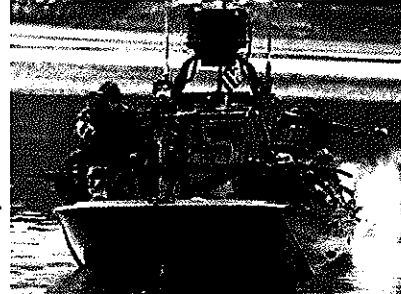
particularly true in applications such as the aircraft production industry where assembly layout and tool selection can reduce worker exposure to awkward postures and hand-arm vibration while improving efficiency. Maintenance and repair costs can be influenced by measures such as selection of low-vibration tools and ongoing tool and equipment upkeep.

Table3 summarizes the potential effects of vibration on acquisition projects.

#### Noise and Vibration Control in Design

- DoD Instruction 5000.2 and SECNAVINST 5000.2D require evaluation of health and safety hazards for all acquisition programs. Relevant sections include: DoD 5000.2 section; 4.3.7.3/SECNAVINST 5000.2D Part 7 section 7.2.1 ("PMs and sponsors shall address HSI throughout all phases of the acquisition process").
- Ergonomic and vibration related sections of OPNAVINST 9640,
- OPNAVINST 5100.23 (Series) and DoD Instruction 6055.12 (Series)

A discussion of control of hand arm vibration in Navy workplaces is provided in *Protecting Our People from Bad Vibrations* (Success Stories section of this website).



The Navy faces the challenge of finding improved vibration-reducing materials and technologies

#### The Programmatic Environmental Safety and Health Evaluation (PESHE) is an ongoing process that requires:

- Assessing environmental and safety regulations that will impact the weapon system throughout its lifetime.
- Identifying safety and health risk factors identified by review of legacy systems and proposed designs along with formal documentation of any decisions to accept those risks.
- Taking action to reduce safety and/or health risk factors. Note: Protective equipment and warning signal/notices are considered the least effective measures and are not considered design controls.

#### Role of Personal Protective Equipment in Vibration Control

Personal protective equipment alone is **not** hazard abatement relative to the acquisition process. OSHA and supporting Navy Instruction OPNAVINST 5100.23 Chapter 5 require that designs abate hazards and allow interim use of protective equipment only where design feasibility and cost considerations preclude exclusive use of engineering controls. System safety and associated hazard abatement tracking (Mil Std 882) also do not consider personal protective equipment as abating a hazard, and require a hierarchy of controls beginning with engineering controls.

Use of gloves meeting ISO 10819 certification criteria for reduction of transmitted vibration is an important mitigating measure in control of vibration transmitted to the hands/arm. Certified anti-vibration gloves must be used in combination with selection of tools and processes designed to minimize or avoid vibration, worker education, medical evaluation and overall process management in order to reduce the risk of hand-arm vibration syndrome.

Use of anti-vibration gloves certified by a third party is essential to be assured of suitable protection. Information on HAV standards is provided in the Vibration Resources section, "Further Reading on Vibration and Vibration Control." Because the Hand Arm Vibration disease begins in the fingers, and because maintaining warm, dry hands to protect against vasoconstriction is essential; products described as "half finger" gloves do not meet ISO/ANSI standard for anti-vibration products and should not be used as "anti-vibration" gloves.

Two certified, US manufactured products have been given global (national stock numbers) and should be available within the Federal supply system. Click here to see a brochure describing these products.

Additionally, one category of certified anti-vibration glove has been made available through GSA Advantage (see the Vibration Resources section) for product information. The GSA advantage process allows vendors to provide products which do not have national stock number (NSNs) to be marketed with the support of the Federal system. It is a more rapid process.

#### Defense Safety Oversight Council-Sponsored Projects

A project to provide improved power hand tools and certified anti-vibration gloves was sponsored by the Defense Safety Oversight Council's Acquisition and Technology Task Force with the support of the Government Services Administration and National Institute for Occupational Safety and Health. A report was presented to the 3rd American Conference on Human Vibration in June 2010. A focused one-year project extension has been funded and initiated in November 2010.

**Note:** Distribution of this information does not constitute product endorsement for a particular vendor or manufacture. However, the product certification has been independently verified.

Other certified anti-vibration gloves are available through a limited number of vendors. Anyone ordering such products should ask the vendor to confirm ISO 10819 certification, as well as considering other performance and comfort factors.

Individual fit and worker preferences as well as adaptation to particular work tasks are key factors to consider in use of any

protective equipment. However, if the products described in this material are suitable for your application, their use should be strongly considered for processes which expose workers to high levels of hand-arm vibration.

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## Discussion

Vibration-related diseases are not new. HAVS was described in U.S. literature as early as 1918, and WBV problems became apparent around 1945. However, vibration-related diseases are often mistaken for other medical conditions and appear to be under reported in the medical literature. In addition, vibration measurements are difficult to perform at times because of the variability of the exposure, complexity of the measuring equipment, and techniques and skill required by the evaluator. The Navy recognizes these problem areas and has sponsored courses that include training on vibration for industrial hygiene and medical personnel. The greatest challenges are vibration recognition, disease prevention, and minimizing vibration exposures. Vibration induced disorders can be minimized by early intervention. The American National Standards Institute (ANSI) and American Conference of Governmental Industrial Hygienists (ACGIH) have developed recommended standards and guidelines, respectively, for exposures to both whole body and segmental vibration. These criteria identify recommended maximum exposures to vibration. The Navy faces the continual challenge of finding better and improved vibration-reducing materials and technologies that meet these guidelines and standards and can be incorporated into ships and shore facility designs during the acquisition process.



Aviation Ordnancemen use a forklift to move weapons and cargo

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## Recommendations

Protecting Navy workers from hazardous *Whole-Body Vibration* means minimizing vibration source generation together with providing a protective whole-body cocoon for exposed workers with follow-up by regularly monitoring the vibration environment while employing sensible work practices. These include:

- Purchasing vehicles with suspension systems that minimize vibration and, where possible, mechanical isolated/floating cabs;
- Purchasing "air-ride seats," (seats provide a protective cushion of air) for both drivers and passengers, as applicable, either as part of an original equipment manufacturer purchase of vehicles and/or;
- Removing non-protective driver's seats from existing vehicles and replacing them with air-ride seats;
- Using air-ride seats for some non-vehicle WBV applications such as hovercraft at sea and in fixed work station situations where the floor vibrates due to functioning equipment processes;
- Adding or designing 'isolators' under machinery to reduce source vibration in some fixed facility situations. This would include foundation mounts that prevent vibration transmission to other structures;
- Incorporating shock mount stand plates, chairs, and vibration dampened controls in acquisition design stages;
- Using good work practices, which include workers taking periodic rest breaks for every one to two hours of continuous WBV exposure and not lifting objects immediately after prolonged WBV exposure, leaving the vehicle using simple egress motions, walking around for a few minutes, and performing other non lifting tasks before attempting any lifting tasks;
- Making workers aware of signs and symptoms of WBV-induced back problems and the need to see their safety managers and health care providers if signs and symptoms occur.

Protecting Navy workers from hazardous Hand-Arm Vibration is multifaceted and begins with minimizing vibration source generation together with providing effective personal protection for exposed workers, regularly monitoring the vibration environment, and employing sensible work practices. These include:

- Purchasing and using only power tools, which are designed to reduce vibration (called AntiVibration, or A/V) and reduce musculoskeletal injuries.

**Important Note:** An ergonomically designed power tool, does not mean the tool has reduced vibration attributes and vice versa; thus power tools which are either A/V designated alone or ergonomically designated alone are not the best choice. The former solution alone, while reducing HAV, can leave tool workers at possible risk for Carpal Tunnel Syndrome, CTS (syndrome of the median nerve and flexor tendons of the hand and wrist). The latter solution alone, while reducing CTS, can leave tool workers at risk for irreversible HAVS.

- Not purchasing or using so-called "vibration reducing tool wraps" which are merely tool handle sleeves that attempt to reduce vibration of conventional power tools. These wraps are generally ineffective and do little to reduce vibration. They also pose an added problem by increasing tool handle diameter, which can possibly lead to cumulative trauma disorders (CTDs) of the forearm, elbow, and shoulder.



- Using only full-finger protected AntiVibration gloves, which meet or exceed the following A/V Glove standard: ANSI S3.40-2002 - ISO 10819. AntiVibration gloves:
  - Must be full-finger protected (no exposed fingers);
  - Must fit well (allowing maximum finger tactility and proper grip);
  - Must keep the fingers and hands warm and dry (to avoid cold-triggered HAVS attacks).
- Using good work practices, including:
  - Letting the power tool do the work;
  - Holding the power tool with the lightest grip possible consistent with safe work practices;
  - Keeping hands and body warm and dry;
  - Not smoking (nicotine, cold, and vibration all constrict blood vessels impeding circulation).
- Maintaining power tools & associated implements in good condition. Otherwise, vibration levels will eventually increase. Thus, regularly scheduled HAV tool monitoring is necessary.
- Making workers aware of HAVS signs and symptoms and the need to see their safety managers and health care providers if signs and symptoms occur.

Further guidance for users of anti-vibration gloves is provided in DoD Ergonomics Working Group News - *Guidance for Users of Anti-Vibration Gloves* and in the Resources section below.

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## References & Best Practices

- Further Reading on Vibration and Vibration Control
- Occupational Vibration Videotapes
- Occupational Vibration Guidelines and Standards
- Occupational Vibration Training & Education
- DoD and Other Safety Websites Dealing with Vibration

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## Further Reading On Vibration and Vibration Control

Health and Safety Executive (HSE)

The European Union has developed regulations for evaluation and management of whole body and hand arm vibration. The United Kingdom's Health and Safety Executive (HSE) (English counterpart of OSHA and NIOSH) provides information on the standard and cost-effective recommendations for control of occupational exposures in varied industries and operations.

Hand Arm Vibration — Just Facts, July 2008

In the U.S. alone about 2.5 million workers are exposed daily to Hand-Arm Vibration [HAV] from the power tools they use on their jobs.

#### Hand-Arm Vibration Standards: The New ANSI S2.70 Standard

Article by Donald Wasserman, MSEE, MBA describing HAVS, the history of hand arm vibration safety standards, and the background, terminology, and provisions of ANSI Standard S2.70.

#### Certified Anti-Vibration Gloves

Photos and sources of certified anti-vibration gloves.

#### GSA Advantage Certified Glove

One category of certified anti-vibration glove has been made available through GSA Advantage (see [www.gsadvantage.gov](http://www.gsadvantage.gov)). The GSA advantage process allows vendors to provide products which do not have national stock numbers (NSNs) to be marketed with the support of the Federal system. **Note:** Distribution of this information does not constitute product endorsement for a particular vendor or manufacture. However, the product certification has been independently verified.

#### Procurement Criteria to Minimize Hand-Arm Vibration Risk

Description of project to identify criteria and procurement guidelines for anti-vibration gloves and power hand tools which will eliminate or at least reduce workplace hand-arm vibration injuries.

#### A Guide to Users of Anti-Vibration Gloves

From the DoD Ergonomics Working Group Newsletter of October 2009

#### High Speed Craft Human Factors Engineering Design Guide

Designed for Naval Architects, Academia, Procurement Agencies, Regulatory Bodies, and Human Factors Subject Matter Experts (see page 3).

Source: High Speed Craft Human Factors & Craft Design web forum

#### Hand Arm Vibration Threshold Limits," DoD Ergonomics Working Group News, Issue 55, August 2006

Measuring exposure levels of hand-arm vibration is a complicated process. An instrument called an accelerometer is used to measure the vibration present from a power tool and then converts it to a proportional electrical output. This output signal is modified to account for the range of frequencies that are particularly harmful to the hand and arm.

#### NIOSH Power Tools Database

NIOSH recently released a Power Tool Database that can be used to find such information as sound power levels, sound pressure levels, and downloadable exposure and wave files related to commonly used power tools.

"Occupational Vibration Exposure-Ch. 4" in Physical & Biological Hazards of the Workplace, 2nd.Ed. [P.Wald & G. Stave, Eds.], Wiley Pub., New York, 2002.

"Occupational Vibration-Ch. 105 in Patty's Toxicology, 5th.Ed [E.Bingham, B. Cohrssen, & C. Powell, Eds.], Wiley Pub., New York, 2001.

"Hand-Arm Vibration: A Comprehensive Guide for Occupational Health Professionals-2nd.Ed., P. Peimear & D. Wasserman, OEM, Medical Press, Beverly Farms, MA, 1998. [ISB 1-88-3595-22-3]

"Musculoskeletal Disorders & Workplace Factors", NIOSH, Pub. #97-141, Cinti., 1997.

"Human Aspects of Occupational Vibration", D. Wasserman, Elsevier Pub., New York, 1987.

#### Vibration Syndrome

NIOSH Current Intelligence Bulletin #38, Pub. #83-110, Cinti., 1983.

#### U.S. Army Combat Systems Test Activity (Aberdeen Test Center) - Aberdeen, MD: Data Analysis

To accommodate the large volume of data collected during vehicle testing, CSTA has developed software for anomaly analysis in near real time. The Vibration Expert System Analyzer (VESA) is a series of C programs that performs the quick look function and recommends continuing or halting the test to correct a problem with the data acquisition system.

Best Manufacturing Practices: Guideline Documents: NAVMAT P-9492:  
Random Vibration

Third American Conference on Human Vibration Abstracts

#### Protecting Our People from Bad Vibrations

Success story and discussion of control of hand arm vibration in Navy workplaces

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## Occupational Vibration Videotapes

"WHOLE-BODY VIBRATION & THE SPINE", 12 minutes, from: Univ. of Iowa, [attn. D. Wilder], Dept. Biomedical Engr., 1408 SC, Iowa City, IA 52242-1088 [email: wilder@engineering.uiowa.edu]

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## Occupational Vibration Guidelines and Standards

American Conference of Government Industrial Hygienists, 1330 Kemper Meadow Drive, Cincinnati, Ohio 45240-1634, ph. 513-742-2020, FAX 513-742-3355.

Threshold Limit Values for Chemical & Physical Agents: Whole-Body Vibration -TLV; Hand-Arm Vibration-TLV

American National Standards Institute [ANSI]

- Antivibration Glove Standard: ANSI S3.40-2002 - ISO 10819
- Hand-Arm Vibration Standard: ANSI S3.34-1986
- Whole-Body Vibration Standard: ANSI S3.18-1979

National Institute for Occupational Safety & Health [NIOSH]

Publications Dept., DSDTT, 4676 Columbia Parkway, Cincinnati, Ohio 45226-1998, ph. 1-800-35-NIOSH, 513-533-8287

- Criteria for a Recommended Standard: Occupational Exposure to Hand-Arm Vibration, NIOSH Publication #89-106

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## Occupational Vibration Training & Education

Through its 16 university-based Education and Research Centers (ERCs), NIOSH supports academic degree programs and research training opportunities in the core areas of industrial hygiene, occupational health nursing, occupational medicine, and occupational safety, plus specialized areas relevant to the occupational safety and health field. In addition to the academic training programs, NIOSH supports ERC short-term continuing education (CE) programs for occupational safety and health professionals, and others with worker safety and health responsibilities. A current CE course schedule for all NIOSH Education and Research Centers can be accessed at the NIOSH ERC Web site <http://www.niosh-erc.org/>, or by contacting the NIOSH/CDC 800-number 1-800-232-4636 or the NIOSH Publications Office. **Note:** Vibration is NIOSH Course 596.

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## DoD and Other Safety Websites Dealing with Vibration

Defense Safety Oversight Council HAVS Project Forum

{**Note:** This is a password protected website. To gain access, please send an email request to [bustles@ctc.com](mailto:bustles@ctc.com)}.

A forum where users can consolidate and collaborate on various documents related to Hand-Arm Vibration Syndrome (HAVS) as it relates to the DoD Defense Safety Oversight Council (DSOC) Project. This site is meant to provide a central repository of resources (briefings, meeting minutes, correspondence, educational materials, etc.) in a collaborative environment where ideas and knowledge can be shared in efforts to enhance the DSOC goals to provide industrial protection for the Federal workforce. This site is geared to encompass commercial vendors as well as responsible Government agencies regarding their respective roles in protecting against HAVS.

Naval Undersea Warfare Center Division - Keyport, WA : Environmental Testing

Naval Undersea Warfare Center (NUWC) Division Keyport has improved its environmental test area capabilities and procedures. These improvements include an upgrade of the vibration systems, development of new dynamic test fixture designs, and use of a computer-aided status system.

Naval Undersea Warfare Center Division - Keyport, WA : Failure Analysis, Non-destructive Testing, & Chemistry Lab

The failure analysis and testing facility at Naval Undersea Warfare Center (NUWC) Division Keyport was established over 25 years ago and maintains numerous analytical and chemical analysis capabilities run by failure analysis experts. These capabilities include non-destructive testing, gas chromatography, use of a scanning electron microscope, elemental analysis, spectrometry, ion chromatography, chemistry laboratory, microscopy laboratory, microsectioning, hardness and tensile testing, and

thermocycling and vibration testing.

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### How to Contribute

We need input from the Defense Acquisition community to address each of the ten Acquisition Safety challenges that are the subject of this website. Grow with us as we share information on how to meet the above challenges through the Defense Acquisition Process. Through the exchange of ideas, information resources, and improvements in methodology and design, these challenges can and will be met.

To submit general information or information on Best Practices, or to submit a success story, please send an email to [safe-webmaster@navy.mil](mailto:safe-webmaster@navy.mil) with the subject line "Acquisition Safety."

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# Study about the human body response under the vertical vibrations action into a vehicle

by Simona Rodean, Mariana Arghir

## Comments

**Abstract:** This paper investigates the biodynamic response of human body subjected to vertical vibrations into an auto vehicle, in two different situations: the driver sitting on a rigid seat and respectively the driver sitting on a vehicle seat with seat cushion and additional seat suspension. In doing so, a seat suspension model with a detailed lumped parameter model of the human body, was developed. The human body can be considered as a mechanical system and it may be roughly approximated by a linear lumped parameter at low frequencies and low vibration levels. The lumped parameter model of the human body consists of four parts: pelvis, upper torso, viscera and head. The seat suspension is formed by spring and dashpot. **Key words:** mechanical model, biodynamic response, vertical vibrations, seats suspension.

## 1. INTRODUCTION

In vehicle systems occupational drivers might expose themselves to vibration for a long time. Whole-body vibration (WBV) occurs when the mechanical vibration from the vehicle is transmitted to the vehicle occupants. The amount of vibration exposure depends on a number of factors, including the type and design of the vehicle, the speed at which the vehicle is traveling, the environmental conditions, and the body posture. Repeated and prolonged exposure to vibration has been linked to fatigue, pain and even injury over time

Recently, the ride comfort and safety for both vehicle drivers and passengers has become a critical issue in vehicle design. It is desirable to isolate the driver and passengers from road induced shock and vibration during transport in order to increase the ride comfort. Therefore, seat suspensions for vehicles are inevitably needed to attenuate and mitigate the whole-body vibration and shock, which is transmitted from the floor of the vehicles to the operator and passengers.

Vibration may be sinusoidal (containing only a single frequency) or complex (containing multiple frequencies). In practice, vibration exposure is always complex, although there may be certain frequencies that are dominant. The vibration frequency range that is considered important for health, comfort and perception is between 0.5 and 80 Hz (ISO 2631-1: 1997); the discussion will be limited to

this frequency range, in this paper. Vibration has been shown to have a negative effect on complex cognitive tasks; however, vibration frequency or magnitude dependencies have not been proved.

The majority of the studies use vertical (z-axis) vibration rather than horizontal (x--and y-axes) vibrations.

However, the relationships between vibration frequency and magnitude vs. performance are unclear.

Using the mechanical model of the human body in a sitting position, we want to show the importance of cushion properties and seat suspension for a comfortable seat vehicle.

In this study, there are a comparison between the eigenvalues of the system made by the human sitting upright on the rigid seat and the eigenvalues from the same mechanical model of the human body sitting upright on the seat cushion, represented by mass [M.sub.1], spring [K.sub.2c] and damping [C.sub.2c]

## 2. MECHANICAL MODEL OF THE HUMAN BODY / SEAT ASSEMBLY

Automotive driver/passenger comfort is strongly influenced by the perception of whole-body vehicular vibration, which is further related to the body posture, static and dynamic properties of the seat, and characteristics of vibration at the body-seat interface.

The mechanical response of the human body can be predicted using a biomechanical model in a vibrating environment such as the driving vehicle.

This study developed a linear biomechanical model of the human body for evaluating the vibration transmissibility and dynamic response to vertical vibrations in sitting posture. For the human body/seat system model, the 4-DOFs model of the human body, proposed by Payne and Band (1971) (Figure 1) is used. This model will help in simulating ride quality and designing the vibration isolator, i.e. seat.

The biomechanical model consists of several lumped masses connected by linear springs and dampers. Considering the human body as a mechanical system it may, at low frequencies (less than 100 Hz) and low vibration levels, it may be roughly approximated by linear lumped parameter systems. The lumped parameter systems comprising masses [M.sub.i], springs [K.sub.i] and dampers [C.sub.i] for  $i = 2, 3, 4$  and 5, [y.sub.i] ( $i = 2, 3, 4, 5$ ) coordinates are the displacement of the human body for pelvis, upper torso, viscera and head, respectively. The soft seat cushion was implemented as a linear spring [K.sub.2c] and damper [C.sub.2c] system. The mass of the moving part of the seat, [M.sub.1], was estimated at about 13,5 kg. The seat is fixed to the floor through the seat suspension which is formed by the spring and dashpot and is represented by the spring [K.sub.1] =  $2.26 \times 10^4$  N/m and damping [C.sub.1] = 750 Ns/m (Figure 2). The human linear parameters given in the literature are presented in Table 1.

## 3. THE MOTION DIFFERENTIAL EQUATIONS

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